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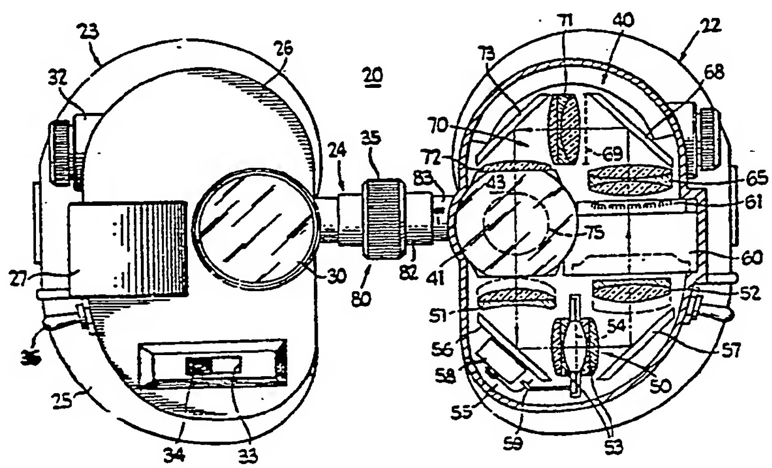

(57) Abstract

The goggles (20, 120) include a pair of optical assemblies (40, 140) each having two intersecting optical paths, including a see-through path with a large field of view of a straight line of sight to the viewed object, and a folded path which includes an objective lens set (50, 150) an intensifier (60) which converts visible and infrared light to a visible intensified light, and an eyepiece lens set (70, 170) arranged in a loop in a plane perpendicular to the see-through path. Infrared and visible light from the viewed objected enters both paths. A dichroic prism combiner (46, 141) at the intersection of the paths reflects intensified light from the folded path into the see-through path and transmits all other light. In one embodiment a dichroic prism separator (42) is disposed at the intersection of the paths forward of the combiner for transmitting a portion of the incoming visible light along the see-through path and reflecting the remainder of the incoming light to the folded path. In another embodiment, the entrance to the folded path is spaced from the see-through path.

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OBJECTIVE LENS SYSTEM, RELAY LENS SYSTEM, AND EYEPIECE LENS SYSTEM FOR NIGHT-VISION GOGGLES

BACKGROUND OF THE INVENTION

The present invention relates to night vision systems of the type which permit vision under low light conditions by intensifying incoming infrared and/or visible light from an object and converting it to an intensified visible light. The invention has particular application to night vision systems of the binocular goggles type, which can be mounted on a viewer's head covering his eyes. One of the main applications of night vision systems are military in nature, and the goggles of the present invention is intended, as one of its main uses and applications, for aircraft pilots, though myriad other uses are possible and practicable, such as police, fire, commercial aviation applications, military aircraft, and night-blind people.

Existing night vision goggles are heavy, cumbersome and unstable. They do not even resemble common goggles, but rather resemble television cameras mounted on the viewer's head, protruding more than 175 mm from the viewer's eye, and weighing as much as 850 grams. The weight and front-to-back length of such systems exert large moments on the viewer's head, causing serious instability problems and preventing effective use of the systems in applications where the head is subjected to gravitational or centrifugal loads.

Night vision systems typically include an objective lens set, an image intensifier and an eyepiece lens set, all arranged in a straight line. The lens design may be such as to result in an inverted image at the viewer's eye. Correction of this condition by the addition of a further inverting lens set would only add to the already excessive length of the system, aggravating the instability problem. Accordingly, the condition is corrected by the use of twisted fiber optics in the intensifier. But such twisted fiber optics have a greater overall optical length, result in a more costly image intensifier and impair the registration or alignment of the two binocular channels.

Additionally, existing night vision goggles cannot handle sudden excessive lighting conditions, such as flares or other bright lights. In such conditions, the goggles become inoperative and must be turned off. When the intensifier is turned off, most prior systems become opaque, rendering the viewer essentially blind. It is known to provide night vision goggles wherein the main optical assembly is coupled to the user's eye through a periscope-type arrangement, the reflection to the viewer's eye being provided by a beam splitting prism which is transparent when the system is turned off, permitting the viewer to look past the main optical assembly. But such arrangements still suffer from all of the other disadvantages discussed herein.

Furthermore, prior systems have an extremely limited field of view with little or no peripheral vision.

This renders such systems essentially useless for applications requiring peripheral vision, such as in police work where the viewer is driving an automobile or other vehicle, and must be able to view the instrument panel without significant head movement.

SUMMARY OF THE INVENTION

It is a general object of the present invention to provide an improved night vision apparatus which avoids the disadvantages of prior devices while affording additional structural and operating advantages.

An important object of the present invention is to provide an image intensifying night vision apparatus which has relatively low mass and short front-to-back dimensions, resulting in improved stability.

Another object of the invention is the provision of a night vision system of the type set forth which also has a see-through capability which renders the system substantially transparent when the intensifier is turned off.

In connection with the foregoing objects, it is another object of the invention to provide a night vision system of the type set forth, which provides a peripheral transparent or see-through field of view when the intensifier is turned on.

Yet another object of the invention is the provision of night vision system which remains operative in sudden high light conditions.

In connection with the foregoing objects, it is still another object of the invention to provide a night vision apparatus of the type set forth, which affords these advantages while permitting use of straight fiber optics in the intensifier.

These and other objects of the invention are attained by providing in night vision apparatus for receiving at an entrance plane visible and infrared light from a viewed object and forming an intensified image of the object along a viewing axis of a viewer's eye, the improvement comprising: means defining an optical path from the entrance plane to the viewer's eye, the optical path having a first portion which lies along the viewing axis and a second portion which is entirely non-parallel to said first portion and image intensifying means disposed in the second portion of the optical path.

The invention consists of certain novel features and a combination of parts hereinafter fully described, illustrated in the accompanying drawings, and particularly pointed out in the appended claims, it being understood that various changes in the details may be made without departing from the spirit, or sacrificing any of the advantages of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

For the purpose of facilitating an understanding of the invention, there are illustrated in the accompanying drawings a preferred embodiments thereof, from an inspection of which, when considered in connection with

the following description, the invention, its construction and operation, and many of its advantages should be readily understood and appreciated.

Figure 1 is a perspective view of night vision goggles constructed in accordance with and embodying the features of a first embodiment of the present invention;

Figure 2 is a front elevational view in partial vertical section of the goggles of Figure 1;

Figure 3 is a view in horizontal section taken along the line 3-3 in Figure 2;

Figure 4 is a diagrammatic view of the optical assembly and paths therethrough in the right-hand portion of the goggles of Figure 1;

Figure 5 is a perspective view of the dichroic prism set of the goggles of Figure 1;

Figure 5 is a graph of the reflectance characteristic of one of the dichroic surfaces of the prism set of Figure 5;

Figure 7 is a graph of the reflectance characteristic of the other dichroic surface of the prism set of Figure 5;

Figure 8 is a side elevational view of the goggles of Figure 1 mounted on the head of the user, illustrating the intensified and transparent fields of view;

Figure 9 is a front view of the fields of view illustrated in Figure 8;

Figure 10 is a view similar to Figure 1, illustrating goggles in accordance with a second embodiment of the present invention;

Figure 11 is a view similar to Figure 2, illustrating the goggles of Figure 10; and

Figure 12 is a diagrammatic view, similar to Figure 4, illustrating the optical assembly and paths therethrough of the right-hand portion of the goggles of Figure 10.

Figure 13 is a front elevational view in partial vertical section of the goggles of the present invention showing in detail the individual lens components and their spacing for each of the objective lens system, the eyepiece lens system, and the relay lens system.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Figures 1-3, there is illustrated a pair of night vision goggles, generally designated by the numeral 20, constructed in accordance with and embodying the features of a first embodiment of the present invention. The goggles 20 include a housing assembly 21 which comprises a pair of housings 22 and 23 arranged for respectively covering the left and right eyes of a viewer and interconnected by a bridge 24. The housing 22 and 23 are constructed as mirror images of each other, and each includes an encompassing peripheral side wall 25 closed at the front end thereof by a flat planar front wall 26. A part-cylindrical portion 27 projects forwardly and laterally outwardly from the housing generally centrally of the junction between the outer side edge of the front wall 26 and the peripheral side wall 25. The rear edge of the peripheral side wall 25 is provided with a face

cushion 28 of suitable resilient material, such as a foam rubber or the like. The face cushion 28 extends around substantially the entire perimeter of the side wall 25 except for the inner side edge thereof adjacent to the wearer's nose. The rear ends of the housing 22 and 23 are interconnected by a head strap 29 for mounting the goggles 20 on the viewer's head in standard fashion, with the housings 22 and 23 respectively covering the viewer's eyes, as indicated in Figure 8.

Each of the housings 22 and 23 also has a circular input window 30 in the front wall 26 thereof adjacent to the inner side edge thereof, the window 30 being formed of a suitable transparent material such as glass or plastic. A battery cartridge 31 is mounted in a battery receptacle boss 32 on the outer side of the peripheral side wall 25. A rectangular slot 33 is formed in the front wall 26 adjacent to the lower end thereof and slidably receives a focusing knob 34 for providing continuous focusing of certain optical components of the goggle 20, as will be explained more fully below. The bridge 24 carries a knurled control wheel 35, the function of which will be explained below, and a power switch 36 is mounted on the peripheral side wall 25 for selectively connecting and disconnecting the battery cartridge 31 from an optical assembly 40 mounted within the housing 22 or 23.

Referring now more particularly to Figs 2, 3 and 5, each of the housings 22 and 23 contains an optical assembly 40. The two assemblies 40 are arranged as

mirror images of each other, the optical assembly 40 for the left eye housing 22 being illustrated in Figure 2. The optical assembly 40 includes a separating/combining prism set 41, which is diagrammatically illustrated in Figure 5. The prism set 41 includes a separating prism 42 and a combining prism 46, each being of the dichroic beam splitting type. More specifically, the separating prism 42 includes an input surface 43, a separating surface 44 and an output surface 45, whereas the combining prism 46 includes an input surface 47, a combining surface 48 and an output surface 49.

The prisms 42 and 46 are arranged so that the separating and combining surfaces 44 and 48 are disposed in facing parallel relationship with a predetermined small gap therebetween to avoid interference with visible light transmission. In this configuration, the input surface 43 is arranged parallel to the output surface 49, while the input surface 47 is arranged parallel to the output surface 45. While, for clarity of illustration, the prisms 42 and 46 have been diagrammatically illustrated with rectangular surfaces in Figure 3, it will be appreciated that, in practice, the prism set 41 has a somewhat conical configuration, with the input surface 43 and the output surface 49 being substantially circular in shape, and the input surface 47 being generally trapezoidal in shape, as indicated in Figures 2 and 3, with the input surface 43 disposed immediately behind the window 30.

In practice, incoming visible and infrared light from a viewed object enters the prism set 40 through the

input surface 43. At the separating surface 44, a portion of the light is transmitted to the combining prism 46 and out through the output surface 49, while the remainder of the light is reflected out through the output surface 45. In like manner, when light enters the input surface 47, upon striking the combining surface 48, a portion is transmitted to the prism 42 and out through the output surface 45, while another portion is reflected out through the output surface 49.

The optical assembly 40 also includes an objective lens set 50 of separated groups, including lens groups 51 and 52 and a pair of lens groups 53 separated by an iris 54 of an automatic light control assembly 55. A mirror 56 is disposed between the lens group 51 and one of the lens groups 53, while another mirror 57 is disposed between the other lens group 53 and the lens group 52, so that the optical path is in the direction indicated by the arrows in Figure 2. The automatic light control assembly 55 includes a motor 58 electrically connected to the battery cartridge 31 and mechanically connected by a linkage 59 to the iris 54. The motor 58 is also electrically connected to an image intensifier 60 which is mounted adjacent to the lens group 52. The image intensifier 60 is of standard construction, and includes circuitry for sensing the intensity of the light passing therethrough and providing to the motor 58 a feedback signal proportional to such intensity. For intensities above a predetermined level, the motor 58 will be actuated

to close the iris 54 a sufficient amount to reduce the light passing therethrough to an acceptable level.

The image intensifier 60 is preferably an 18 mm microchannel wafer-type image intensifier, with a straight fiber optics output window 61. In operation, the image intensifier 60 receives incoming visible and infrared light from the objective lens set 50 and intensifies it, converting it to a visible output light in a predetermined narrow band of wave lengths. In a preferred embodiment, the output light from the image intensifier 60 is emitted by a green phosphor, producing a visible band of light which is known as "P-20" light, although it will be appreciated that image intensifiers 60 producing other output wave lengths could also be used.

The output from the image intensifier 60 is applied to a relay lens group 65, producing a secondary image which is reflected from a mirror 68 to an image plane 69. This image then passes through an eyepiece lens set 70, which includes a lens group 71 and a plano convex lens 72, a mirror 73 being interposed therebetween. The output of the eyepiece lens set 70 then passes into the combining prism 45 through the input surface 47 thereof.

The optical assembly 40 also includes a diopter adjusting lens 75 (Figure 3) which is preferably a lens group and is carried in a circular holder 76, which is threadedly engaged in the rear end of a generlly conical housing receptacle 77 in the housing 22 (or 23). The diopter adjusting lens 75 is, therefore, disposed

immediately adjacent to the output surface 49 of the combining prism 46, and may readily be replaced with other adjusting lenses, depending upon the diopter requirement of the particular viewer's eye.

The bridge 24 carries an interpupillary adjustment assembly 80 which includes a pair of coaxial, externally threaded inner tubes 81, respectively connected to the housings 22 and 23, and an internally threaded outer tube 82 which is threadedly engaged with each of the inner tubes 81 and is encircled by and fixedly secured to the knurled control wheel 35. Preferably, a micrometer scale 83 is imprinted on the outer surface of one or both of the inner tubes 81 to indicate the interpupillary distance between the optical assemblies 40. Disposed within the inner tubes 81 is a helical wound electrical wire 84 which pwoers both housings 22 and 23 from one electrical switch 36. By rotation of the outer tube 82 by use of the knurled wheel 35, the inner tubes 81 are moved axially toward and away from each other to vary the interpupillary distance to match that of the particular viewer who will be wearing the goggles 20.

The reflectance characteristic of the coating on the separating surface 44 of the prism 42 is illustrated in Figure 5, which is a plot of percent reflectance against wave length in nanometers. The reflectance characteristic is indicated by the curve 90, which lies in a range between upper and lower limits designated, respectively, by the broken lines 91 and 91a, depending upon the quality of the dichroic coating on the

separating surface 44. It can be seen that the separating surface 44 reflects approximately 50% of the wave lengths in the visible spectrum, between about 400 and 700 nm, as indicated by the generally horizontal portion 92 of the curve 90, the remainder of the incident visible light being transmitted through the separating surface 44. The curve 90 has a substantially vertical portion 93 at about 700 nm, all higher wave lengths being substantiall completely reflected, as indicated by the upper portion 94 of the curve 90. These wave lengths above 700 nm represent the infrared portion of the spectrum and, in practice, between 90% and 100% of the incident infrared light is reflected by the separating surface 44, depending upon the quality of the dichroic coating thereon. Any unreflected infrared light is, of course, transmitted through the separating surface 44. Preferably, the dichroic coating is selected so that at least 50% of the visible light is transmitted.

The reflectance characteristic of the coating on the combining surface 48 is illustrated in Figure 7 by the curve 95, which lies in a range between upper and lower limits respectively designated by the broken lines 96 and 96a. The combining surface 48 selectively reflects a narrow band of wave lengths less than 100 nm in width, between the steep sides 97 of the curve 95, the band being centered at 550 nm at the peak 98, which is the wave length of the P-20 light emitted from the image intensifier 60. It can be seen that between 75% and 100% of this P-20 light at the peak 98 will be reflected,

depending upon the quality of the dichroic coating on the combining surface 48. Wave lengths below 500 nm and above 600 nm are substantially completely transmitted through the combining surface 48, as indicated by the feet 99 of the curve 95. However, since only P-20 light is emitted from the image intensifier 60, therefore only P-20 light enters the input surface 47 of the prism 46, substantially all of this light being reflected out through the output surface 49. In order to prevent the small portion of P-20 light that is transmitted through the combining surface 48 from entering the objective lens set 50, a pair of polarizing filters (not shown) could be applied respectively on the input surface 47 and the output surface 45.

The approximately 50% of the visible light transmitted through the separating surface 44 will suffer some additional loss in passing through the combining surface 48. However, this loss can be minimized by the use of a holographically formed coating on the combining surface 48 by techniques known to those skilled in the art.

Referring now in particular to Figures 2, 3 and 4, the operation of the optical assembly 40 will be explained in detail. Figure 4 shows a diagrammatic representation of the optical assembly 40 and the light paths therethrough for the right eye housing 23, but it will be appreciated that the corresponding diagram for the optical assembly 40 in the left eye housing 22 would simply be a mirror image. The entire spectrum of light

from the viewed object, including visible and infrared light, enters the optical assembly 40 at an entrance plane defined by the window 30. This light enters along a see-through path 100 having a front portion 101 forward of the prism set 41 and a rear portion 102 rearward of the prism set 41. It can be seen that the see-through path 100 is a straight-line path along the viewing axis of the viewer's eye, which lies along the line of sight from the viewer's eye to the viewed object.

When this light strikes the separating surface 44 of the separating prism 42, approximately 50% of the visible light and virtually all of the infrared light is reflected downwardly along a vertical leg 104 of a folded intensified light path 105, which defines a loop lying in a plane substantially perpendicular to the see-through path 100. The reflected light in the folded path 105 is reflected from the mirror 56 along horizontal leg 106 and then from the mirror 57 into a vertical leg 107, in the direction indicated by the arrows in Figure 4. The objective lens set 50 is, for convenience, diagrammatically illustrated in the leg 106 although, as can be seen from Figure 2, the objective lens set 50 actually includes separated lens groups which are disposed on either side of the mirrors 56 and 57.

The light that is reflected into the leg 107 passes through the image intensifier 60, being converted to an intensified P-20 light, which then passes through the relay lens group 65. The output from the relay lens group 65 passes through the eyepiece lens set 70 to the

input surface 47 of the combining prism 46, being reflected en route by the mirror 68 into a horizontal leg 108 and thence by the mirror 73 to a descending leg 109 of the path 105. While, for convenience, the eyepiece lens set 70 is diagrammatically illustrated in the leg 108, it will be understood that it comprises separated elements which are disposed on either side of the mirror 73.

When the P-20 light arrives at the combining surface 48 of the prism 46, it is substantially all reflected into the rear portion 102 of the see-through path 100 through the output surface 49, joining the approximately 50% of the visible light which was transmitted through the separating prism 42. This combined light is then passed through the diopter adjustment lens 75 to the viewer's eye.

The purpose of the relay lens group 65 is to invert the image from the image intensifier 60 to complement an inversion effected by the objective lens set 50, thereby insuring that an erect image will be presented to the viewer's eye. Alternatively, it will be appreciated that twisted fiber optics could be used in the image intensifier 60 to effect the necessary image inversion, although this has attendant disadvantages, as explained above.

It is a fundamental aspect of the present invention that the unique arrangement of the optical assemblies 40 results in goggles 20 with significantly reduced front-to-back dimensions. More particularly, most of each optical assembly 40 is arranged in the folded path 105

which lies in a plane disposed perpendicular to the viewing axis. The only optical components disposed along the viewing axis are the separating/combining prism set 41 and the diopter adjusting lens 75. This results in a goggles housing assembly 21 which has a total front-to-back depth of only about 70 mm as opposed to prior art devices with depths in excess of 175 mm. Additionally, the total weight of the goggles 20 is only about 350 grams, as opposed to weights between 650 and 850 grams for prior night vision goggles. The significantly reduced mass and depth of the goggles 20 results in a vastly reduced moment relative to the viewer's eye of about 730 g/cm, as compared with moments of about 6000 g/cm for prior goggles. Thus, the present invention provides greatly enhanced stability in use.

Another significant feature of the invention is that it offers the aforementioned stability, while at the same time providing a see-through capability. Thus, the use of beam splitting prisms 42 and 46 in the see-through path 100 along the viewing axis which are at least 50% transparent to visible light, permits a viewer to see through the goggles 20 even when the image intensifiers 60 are turned off. Accordingly, the viewer can turn on the image intensifiers 60 only when they are needed, thereby significantly reducing power consumption and battery drain.

Furthermore, another significant aspect of the invention is that the optical assemblies 40 are designed so that the transparent or see-through field of view is

significantly greater than the intensified field of view, thereby affording the viewer significant unintensified peripheral vision, when the image intensifiers 60 are turned on. Referring in particular to Figures 3, 8 and 9, the size of the output area of the image intensifier 60 (about 18 mm) and the focal length of the eyepiece lens set 70 are such that there is formed on the input surface 47 of the combining prism 46 an intensified image area 110 (Figure 3). This affords a circularly conical intensified image field of view 111 of substantially 45 degrees. More specifically, the intensified image field of view 111 has a substantially conical boundary 112 which is substantially coaxial with the viewing axis along the see-through path 100. This is about the same angle intensified field of view as is afforded by prior night vision goggles.

However, the prism set 41 is designed with external dimensions such as to provide a transparent image field of view 115 which is substantially greater than the intensified image field of view 111. More particularly, the transparent image field of view 115 is coaxial with the intensified image field of view 111 and has a circularly conical outer boundary 117 with a conical angle of at least 80 degrees, and preferably 90 degrees. Thus, the conical angle of the transparent image field of view 115 is approximately twice that of the intensified image field of view 111, affording transparent or see-through vision extending 45 degrees above and below the viewing axis.

It will be appreciated that the area between the outer boundary 112 of the intensified image field of view 111 and the outer boundary 117 of the transparent image field of view 115 affords an annular peripheral vision field of view. This peripheral vision field of view is adequate, for example, to permit the viewer to see an instrument panel 118 of an aircraft, or the like, by a simple movement of the eyes. In this regard, the fiberoptic output window 61 of the image intensifier 60 may be truncated, as indicated in Figure 3, to produce a cutoff lower edge 119 of the intensified image field of view 111 (Figures 8 and 9) to prevent the intensified image field of view from overlapping objects, such as the instrument panel 118, in the peripheral vision field of view. In the preferred embodiment, the cutoff lower edge 119 is positioned so that the intensified image field of view 111 extends approximately 17 degrees below the viewing axis. It will be understood that, when the image intensifier is turned off, the entire transparent image field of view 115 is transparent to approximately 50% of the incoming visible light from the viewing object.

Another aspect of the invention is that the automatic light control assembly 55 insures that the goggles 20 will be operative in sudden excessive lighting conditions, such as in the presence of flares or the like. Thus, as soon as the excessive lighting condition is sensed by the image intensifier 60, it sends a feed-back signal to the motor 58 for closing the iris 54 the necessary amount. In the preferred embodiment the

automatic light control assembly 55, which is of known construction and may be of the type used in SLR and movie cameras, has a minimum aperture ratio of 1,000:1. In addition, the optical assembly 40 could be designed to provide anti-laser protection. Thus, one or more of the optical elements in the folded path 105 may be made of Schott KG-3 glass, which is capable of absorbing up to 99.9% of 1064 nm laser energy.

In the preferred embodiment of the invention, the optical assembly 40 is designed to have a magnification of 1.00 and a resolution of .61 lines per milliradian, and the focus range of the objective lens set 50 is from 25 cm to infinity. The objective lens set 50 forms a lens with an aperture of f/1.2 and t/1.65 and with an effective focal length of 21.7 mm. The eyepiece lens set 70 has an effective focal length of 22.8 mm and an exit pupil diameter D (Figure 3) of 7.5 mm.

The diopter adjustment is preferably between +2 and -6 diopter. The interpupillary distance is adjustable between 51 and 72 mm and the eye relief, i.e., the axial distance between the viewer's eye and the diopter adjusting lens 75, is 13 mm when the goggles 20 are properly seated over the viewer's eyes. The overall dimensions of the goggles 20 are 95 mm height X 160 mm width X 70 mm depth, and they protrude only 40 mm from the viewer's eye.

Referring now to Figures 10-12, there is illustrated another embodiment of the goggles of the present invention, generally designated by the numeral 120. The goggles 120 are similar to the goggles 20 and

common parts bear the same reference numerals. The goggles 120 include a housing assembly 121 having left and right eye housings 122 and 123 which are fundamentally the same as the housings 22 and 23 described above, except that they have a slightly greater height, preferably about 110 mm. Each of the housings 122 and 123 has a large input window 130 which is substantially the same as the input windows 30 described above, and immediately therebelow a small input window 137. The windows 130 and 137 preferably overlap slightly along a truncation line 138.

Each of the housings 122 and 123 has an optical assembly 140, which differs in only a few respects from the optical assemblies 40 described above. More particularly, the optical assembly 140 includes a mirror 145 immediately behind the input window 147 for reflecting all of the incoming light downwardly to an objective lens set 150, which is substantially the same as the objective lens set 50 described above, except that its first element is a lens group 151. The optical path then proceeds through the image intensifier 60 to a relay lens set 165 comprising a plurality of separated elements 166, 167 and 168. The relay lens set 165 serves the same function as the relay lens group 65, above, i.e., to invert the image from the image intensifier 60. The optical path then extends through an eyepiece lens set 170, which includes a lens group 171 between the mirrors 68 and 73, and a plano-convex lens element 172. Immediately beneath the lens element 172 and behind the

input window 130 is a combining prism set 141 which is substantially identical to the prism set disclosed above with respect to Figures 1-4, except that it has no coating on the surface 44.

Referring to Figures 11 and 12, it can be seen that the optical paths formed by the optical assembly 140 are slightly different from those formed by the optical assembly 40. More particularly, there is a straight-line, see-through path 300 along the viewing axis which passes through the input window 130 and the prism set 141 and the diopter adjustment lens 75 to the viewer's eye. It will be appreciated that both visible and infrared light passes along this path 300, but the infrared light is not visible to the viewer.

The full spectrum of visible and infrared light from the viewed object also enters the input window 137 to a straight line portion 302 of an intensified light path 305, which is disposed substantially parallel to the see-through path 300, but is spaced therefrom a predetermined distance, preferably about 20 mm. All of this light is reflected by the mirror 145 into a folded portion 303 of the path 305, which includes legs 304, 306, 307, 308 and 309, all lying in a plane disposed substantially perpendicular to the see-through path 300. It will be noted that the objective lens set 150 and the eyepiece lens set 170 are, respectively, diagrammatically shown in the legs 306 and 308 of Figure 12, although it will be appreciated that the actual positions of the lens elements are as illustrated in Figure 11. In operation,

the visible and infrared light in the intensified light path 305 is converted by the image intensifier 60 to P-20 light, which is reflected by the prism set 141 into the see-through path 300 and to the eye of the viewer.

Except as just indicated, the operation of the goggles 120 is exactly the same as was described above for the goggles 20. The housing assembly 121 is slightly larger than the housing assembly 21, but the optical assembly 140 is more efficient than the optical assembly 40, since the full spectrum of light from the viewed object passes through the image intensifier 60. The slight separation of the see-through path 300 from the straight-line portion 302 of the intensified light path 305 may cause some parallax at close-up vieweing, but the effect is very minimal.

The optical characteristics of the optical assembly 140 are substantially the same as those described above for the optical assembly 40, except that the aperture of the objective lens set 150 is t1.45. The slightly larger housing assembly 121 weights approximately 400 grams, resulting in a moment relative to the viewer's eye of 850 g/cm.

In Figure 13 there is shown the details of the lens system components of the goggles of Figure 1, where like parts are indicated by like reference numerals. The pair of goggles 200 of Figure 13 differs from that of Figure 1 in that the automatic light control assembly 50 is absent from the goggles 200. Otherwise, the same general features are same, with the pair of goggles 200 showing

the actual system components of each of the objective lens system 50, the relay lens system 65, and the eye-piece lens system 70. The objective lens system 50 is made up of lens components 206, 208, 210, 212, 214, 216 and 218 in Figure 13. The relay lens system 65 is made up of lens components 220, 222, 224 and 228. The eye-piece lens system 70 is made up of lens components 230, 232 and 234.

With attention now to the objective lens system components, the component 206 is a convex lens having an entrance radius of 34.170 mm., and an exit radius of -197.813 mm., with a thickness of 2.3 mm. The index of refraction with respect to the air of the glass of component 206 is 1.834, and has a dispersion value of 373. The clear aperture of the entrance radius is 20.69 mm., and the clear aperture of the exit radius is 20.08 mm. The distance from component 206 to 208 is .100 mm.

Component 208 is a mensicus lens having an entrance radius of 15.740 mm., and an exit radius of -9.3848 mm., with thickness of 1.200 mm. The index of refraction with respect to air of the glass of component 208 is 1.834, and has a dispersion value of 373. The clear aperture of the entrance radius is 14.57 mm., and the clear aperture of the exit radius is 12.60 mm.

Component 210 is also a mensicus lens having an entrance radius of -32.968 mm. and an exit radius of 15.740 mm., with thickness of 3.1 mm. The index of refraction of the glass of the component with respect to

air is 1.713, and has a dispersion value of 538. The clear aperture of the entrance radius is 19.58 mm. and the clear aperture of the exit radius is 20.04 mm. The air space between component 210 and 208 is 24.000 mm. taken along the central axial light path as shown, along the direction from component 208 to mirror 56 to component 210.

Component 212 is a crown lens forming part of the doublet 212-214 for color correction, and has an entrance radius of 187.890 mm., and an exit radius of 15.473 mm., and a thickness of 3.1 mm. The index of refraction of the glass of the component with respect to the air is 1.487, and has a dispersion value of 704. The clear aperture of the entrance radius is 18.61 mm., while the clear aperture of the exit radius is 18.35. The central axial air space between component 212 and component 210 is .100 mm.

Component 214 is a flint lens of the doublet 212-214, and has an entrance radius of -15.473 mm. and an exit radius of 41.483 mm., with a thickness of 1.20 mm. The glass of component 214 has an index of refraction with respect to air of 1.847, with a dispersion value of 238. The clear aperture of the entrance radius is 18.35 mm., and the clear aperture of the exit radius is 18.57 mm. The components 212 and 214 touch one another, and have no central axial air space therebetween.

Component 216 is a convex lens having an entrance radius of 41.923 mm. and an exit radius of 65.345 mm., with a thickness of 2.700 mm. The glass of the lens has

an index of refraction with respect to air of 1.620, and has a dispersion value of 603. The clear aperture of the entrance radius is 18.49 mm. and the clear aperture of the exit radius is 18.52 mm. The central axial air space from component 214 to 216 is .100 mm.

Component 218 is a field flattener lens having an entrance radius of -19.600 mm. and an exit radius of 458.847 mm. The thickness is 1.200 mm., and the index of refraction with respect to air of the glass of the component is 1.806, with a dispersion value of 407. The clear aperture of the entrance radius is 15.65 mm. and the clear aperture of the exit radius is 16.49 mm. The central axial air space from component 216 to component 218 along the axial light path as shown in Figure 13 is 22.000 mm. The air space from component 218 to the input of the intensifier 60 is .2827 mm.

Turning now to the relay system components 220-228, component 220 is a bi-convex lens having an entrance radius of 43.180 mm. and an exit radius of 31.011 mm., with a thickness of 3:000 mm. The glass of the component has an index of refraction with respect to air of 1:834, and a dispersion value of 373. The clear aperture of the entrance radius is 15.94 mm., while clear aperture of the exit radius is 15.67 mm. Component 220 is spaced from the output of the image intensifier by a central axial air space of 1.6244 mm.

Component 222 is a convex lens having an entrance radius of 12.133 mm. and an exit radius of -110.148, with a thickness of 2.000 mm. The glass of the component has

an index of refraction with respect to air of 1.807, and a dispersion value of 316. The clear aperture of the entrance radius is 8.60 mm., while the clear aperture of the exit radius is 7.63. The air space distance from the component 220 to 222 is 7.501 mm.

Component 224 is a meniscus lens having an entrance radius of 4.855 mm., and an exit radius of -3.411 mm., with a thickness of 1.800 mm. The glass of the component has an index of refraction with respect to air of 1.805, with a dispersion value of 255. The clear aperture of the entrance radius is 5.92 mm., and the clear aperture of the exit radius is 3.75 mm. The air space distance between components 222 and 224 is 0.100 mm.

Component 226 is a convex lens having an entrance radius of -42.761 mm. and an exit radius of 7.750 mm., with a thickness of 2.400 mm. The glass of the component has an index of refraction with respect to air of 1.807, with a dispersion value of 316. The clear aperture of the entrance radius is 8.95 mm., while the clear aperture of the exit radius is 9.74 mm. The central axial air space distance between component 224 and 226 is 5.081 mm.

Component 228 is a meniscus lens having an entrance radius of -34.634 mm., and an exit radius of 18.980 mm., with a thickness of 1.400 mm. The glass of the component has an index of refraction with respect to air of 1.807, with a dispersion value of 316. The clear aperture of the entrance radius is 10.37 mm., while the clear aperture of the exit radius is 10.75 mm. The air space distance between components 226 and 228 is 0.100 mm.

Component 230 is a flint lens of the doublet 230-232, and has an entrance radius of -21.361 mm., and an exit radius of -36.000 mm., with a thickness of 1.200 mm. The glass of the lens has an index of refraction with respect to air of 1.805, and a dispersion value of 255. The clear aperture of the entrance radius is 17.93 mm., while the clear aperture of the exit radius is 21.94 mm. The air space distance between components 228 and 230 is 18.566 mm., as taken along the axial light path as shown in Figure 13 as it travels from component 230 to the mirror 68 and thence to the component 230.

Component 232 is a crown lens of the doublet 230-232 used for color correction, and has an entrance radius of 36.000 mm. and an exit radius of 16.492 mm. The thickness of the component is 8.400 mm. The index of refraction of the glass of the component with respect to air is 1.804, with a dispersion value of 465. The clear aperture of the entrance radius is 21.94 mm., and the clear aperture of the exit radius is 23.15 mm. The air space distance from component 230 to 232 is zero.

Component 234 is a plano-convex lens having an entrance radius of 36.471 mm., and a thickness of 3.000 mm. The index of refraction of the glass of the component is 1.806, with a dispersion value of 407. The clear aperture of the entrance radius is 21.52 mm., while the clear aperture of the planar exit radius is 21.14 mm. The distance between components 232 and 234 along the central axial light path shown in Figure 13 is 20.000 mm.

The exit output of the image intensifier 60 has a radius of 18.000 mm.

From the foregoing, it can be seen that there has been provided an improved night-vision goggles which has very low mass and front-to-back depth, resulting in increased stability, and which nevertheless afford see-through vision when the intensifier is off and substantial peripheral see-through vision when the intensifier is on, the goggles also remaining operable in sudden excessive light conditions.

WHAT IS CLAIMED IS:

CLAIM 1. In a night vision apparatus for receiving at an entrance plane visible and infrared light from a viewed object and forming an intensified image of the object along a viewing axis of a viewer's eye, which apparatus comprises an optical path from the entrance plane to the viewer's eye, and having a first portion which lies along the viewing axis and a second portion which is entirely non-parallel to said first portion, image intensifying means disposed in the second portion of the optical path, objective lens means in the second path disposed forwardly of the image intensifying means, and eyepiece lens means disposed rearwardly of the image intensifying means, the improvement comprising:

said objective lens means having at least one convex lens, at least one meniscus lens, a first doublet lens system, and a field flattener lens.

CLAIM 2. The improvement according to Claim 1, wherein said objective lens means comprises a pair of convex lens, one forwardly of said doublet lens system, and one rearwardly thereof.

CLAIM 3. The improvement according to Claim 1, wherein said objective lens means comprises a pair of meniscus lens mounted in said second path at substantially right-angles to each other.

CLAIM 4. The improvement according to Claim 3, wherein said objective lens means comprises a pair of convex

lens, one said convex lens being mounted forwardly of said doublet lens system, and one said convex lens being mounted rearwardly of said doublet lens system.

CLAIM 5. The improvement according to Claim 4, wherein said field flattener lens is mounted forwardly of each of said convex lenses and each of said meniscus lenses, and forwardly of said doublet lens system.

CLAIM 6. The improvement according to Claim 3, wherein said pair of meniscus lenses is mounted forwardly of said doublet lens system.

CLAIM 7. The improvement according to Claim 6, wherein said lenses of said pair of meniscus lenses are separated by a mirror for reflecting the path of light from the first forward-most one of said pair of meniscus lenses to the second rearward-most one of said pair of meniscus lenses; said pair of meniscus lenses being separated by an air space of more than 20 mm., which air space is taken along the path of travel of a central, axial light ray from said first mensicus lens to the mirror therebetween, and therefrom to said second meniscus lens.

CLAIM 8. The improvement according to Claim 4, wherein said field flattener lens is mounted at right-angles with respective to the rearward-most one of said pair of convex lenses.

CLAIM 9. The improvement according to Claim 1, wherein said eyepiece lens means comprises a second doublet lens

system having a flint lens and a crown lens, said crown lens being mounted rearwardly of said flint lens; said second doublet lens system being mounted rearwardly of the image intensifying means.

CLAIM 10. The improvement according to Claim 9, wherein said eyepiece lens means further comprises a plano-convex lens mounted rearwardly of said second doublet lens system at substantially right-angles to said crown lens of said second doublet lens system; said plano-convex lens being positioned directly adjacent to the input surface of the combining prism of the optical path.

CLAIM 11. The improvement according to Claim 1, wherein the improvement further comprises a relay lens means interposed between said objective lens means and said eyepiece lens means, and mounted rearwardly of said image intensifying means, comprising at least one meniscus lens, a bi-convex lens, and at least one convex lens.

CLAIM 12. The improvement according to Claim 11, wherein said relay lens means comprises a pair of meniscus lenses, and a pair of convex lenses, each of said mensicus lenses and convex lenses being mounted rearwardly of said bi-convex lens; said pair of convex lenses being separated by one of said pair of mensicus lenses.

CLAIM 13. The improvement according to Claim 12, wherein the rearward-most one of said pair of convex lenses is separated from the forward-most one of said pair of

mensicus lens by more than 5 mm. of air space taken in the central, axial direction along which a central, axial light ray travels; the rearward-most one of said pair of meniscus lenses being mounted at substantially right-angles with respect to most of said eyepiece lens means.

CLAIM 14. In a night vision apparatus for receiving at an entrance plane visible and infrared light from a viewed object and forming an intensified image of the object along a viewing axis of the viewer's eye, which apparatus comprises an optical path from the entrance plane to the viewer's eye, and having a first portion which lies along the viewing axis and a second portion which is entirely non-parallel to said first portion, image intensifying means disposed in the second portion of the optical path, objective lens means in the second path disposed forwardly of the image intensifying means, and eyepiece lens means disposed rearwardly of the image intensifying means, the improvement comprising:

said eyepiece lens means comprising a doublet lens system having a flint lens and a crown lens, said crown lens being mounted rearwardly of said flint lens; said doublet lens system being mounted rearwardly of the image intensifying means; and a plano-convex lens mounted rearwardly of said doublet lens system; said plano-convex lens being directly adjacent to the input surface of the combining prism of the optical path.

CLAIM 15. The improvement according to Claim 14, wherein the improvement further comprises a relay lens means

interposed between said objective lens means and said eyepiece lens means, and mounted rearwardly of said image intensifying means; said relay lens means comprising a pair of meniscus lenses, a pair of convex lenses, and a bi-convex lens; said pair of convex lenses being separated by one of said pair of meniscus lenses; each of said meniscus lenses and convex lenses being mounted rearwardly of said bi-convex lens and substantially parallel thereto and to each other.

CLAIM 16. An objective lens system for use in a night vision system, which night vision system includes a bent path through which the incoming light travels, comprising, in combination:

a first convex lens through which the incoming beam of light passes;

a first meniscus lens directly adjacent and in close proximity to said first convex lens and parallel thereto;

a first mirror mounted at an angle with respect to said first meniscus lens so that the light from said first meniscus lens may be reflected at an angle with respect to the axis of said first meniscus lens, said first mirror being spaced from said first meniscus lens;

a second meniscus lens downstream of said first mirror and mounted at substantially right-angles to said first meniscus lens, the light from said first mirror being reflected toward said second meniscus lens, said first mirror being mounted at an angle that reflects

substantially all of the incoming source-light through said second meniscus lens;

a doublet lens system for color correction mounted downstream of said second meniscus lens and directly adjacent and in close proximity to said second meniscus lens;

a second convex lens mounted downstream of said doublet lens system directly adjacent and in close proximity to said doublet lens system;

a second mirror mounted downstream of said second convex lens and spaced therefrom, said second mirror being mounted at an angle with respect to the central axis of said second convex lens so as to reflect the light impinging thereon;

and a field flattener lens mounted downstream of said second mirror and at substantially right-angles to said second convex lens, but parallel to each of said first convex lens and said first meniscus lens, whereby the light from the objective lens system is transmitted to the input of an image intensifying means mounted downstream of and directly adjacent to said field flattener lens.

<u>CLAIM 17</u>. The objective lens system according to Claim 16, wherein said first mirror is separated from said first meniscus lens by an air space of more than 12 mm. along the central axial direction; said second meniscus lens being separated from said first mirror by more than 11 mm. along the central axial direction; said second

mirror being separated from said second convex lens by an air space of more than 9 mm. along the central axial direction; and said field flattener lens being separated from said second mirror by an air space of more than 12 mm. along the central axial direction.

CLAIM 18. The objective lens system according to Claim 16, in combination with an image intensifier and a relay lens system, said image intensifier being mounted downstream of said objective lens system and interposed between said objective lens system and said relay lens system.

CLAIM 19. The objective lens system according to Claim 18, wherein said relay lens system comprises a bi-convex lens mounted at the output of said image intensifier; a third convex lens mounted downstream of said bi-convex lens; a third meniscus lens mounted downstream of said third convex lens and directly adjacent and in close proximity thereto; a fourth convex lens spaced from said third meniscus lens and downstream therefrom; and a fourth meniscus lens downstream of said fourth convex lens and mounted directly adjacent and in close proximity to said fourth convex lens; each of said lenses of said relay lens system being parallel to each other and parallel to said field flattener lens of said objective lens system.

CLAIM 20. The objective lens system according to Claim 17, in combination with an image intensifier and an

eyepiece lens system for projecting the image from said image intensifier to the eye of a user of said objective lens system, said eyepiece lens system comprising a second doublet lens system for correcting color mounted downstream of said image intensifier and at substantially right-angles thereto; a third mirror interposed between said image intensifier and said doublet lens system, said third mirror being mounted at an angle with respect to said second doublet lens system so that the beam of light from said image intensifier may be totally reflected to said doublet lens system; and a plano-convex lens mounted at right angles to said doublet lens system and parallel to said first convex lens of said objective lens system, said plano-convex lens having its central axis thereof coplanar with the central axis of said first convex lens; said first convex lens and said plano-convex lens being positioned directly adjacent to opposite, parallel surfaces of a beam-splitting prism means such that the beam-splitting prism means lies between said plano-convex lens and said first convex lens.

CLAIM 21. In night vision apparatus for receiving at an entrance plane visible and infrared light from a viewed object and forming an intensified image of the object along a viewing axis of a viewer's eye, the improvement comprising: means defining an optical path from the entrance plane to the viewer's eye, said optical path having a first portion which lies along the viewing axis and a second portion which is entirely non-parallel to

said first portion, and image intensifying means disposed in said second portion of said optical path.

CLAIM 22. The night vision apparatus of Claim 21, wherein said second portion of said path is disposed substantially perpendicular to the viewing axis.

CLAIM 23. The night vision apparatus of Claim 21, wherein said second portion of said path is folded and lies in a plane inclined with respect to the viewing axis.

CLAIM 24. The night vision apparatus of Claim 23, wherein said plane is disposed substantially perpendicular to the viewing axis.

CLAIM 25. The night vision apparatus of Claim 21, and further incuding lens means disposed in said second portion of said path.

CLAIM 26. The night vision apparatus of Claim 25, wherein said lens means includes objective lens means and eyepiece lens means respectively disposed forwardly and rearwardly of said image intensifying means.

CLAIM 27. The night vision apparatus of Claim 25, wherein said second portion of said path is folded and lies in a plane which is inclined with respect to the viewing axis.

CLAIM 28. Night vision apparatus comprising: input means for receiving visible and infrared light from a

viewed object and directing the light along two intersecting optical paths, one of said paths lying entirely along a straight line and the other of said paths having a folded portion which is entirely non-parallel to said one path, intensifying means disposed along said folded portion of said other path for converting the visible and infrared light therein to a visible intensified light, and means at the intersection of said paths for combining said intensified light with the light in said one path.

CLAIM 29. The night vision apparatus of Claim 28, wherein said folded portion of said other path defines a loop which lies in a plane disposed substantially perpendicular to said one path.

CLAIM 30. The night vision apparatus of Claim 28, wherein said other path has an input portion disposed substantially parallel to said one path.

CLAIM 31. The night vision apparatus of Claim 29, wherein said combining means reflects said intensified light into said one path.

CLAIM 32. The night vision apparatus of Claim 28, wherein said combining means has a field of view for the light in said one path which is substantially greater than the field of view for said intensified light.

CLAIM 33. The night vision apparatus of Claim 32, wherein said two fields of view are substantially

circular and concentric, a non-overlapping portion of the larger field of view defining a peripheral vision field of view for unintensified visible light from the object.

CLAIM 34. The night vision apparatus of Claim 28, and further including objective lens means and eyepiece lens means disposed in said folded portion of said other path respectively forwardly and rearwardly of said intensifying means.

CLAIM 35. The night vision apparatus of Claim 34, and further including means for focusing said objective lens means.

CLAIM 36. The night vision apparatus of Claim 28, and further including diopter adjustment means disposed in said one path rearwardly of said combining means.

CLAIM 37. The night vision apparatus of Claim 28, and further including automatic light control means disposed in said other path forwardly of said intensifying means and electrically coupled thereto and responsive to a feedback signal therefrom for automatically reducing the amount of light transmitted to said intensifying means when the intensified light exceeds a predetermined level.

CLAIM 38. Night vision apparatus comprising: input means for receiving incident visible and infrared light from a viewed object and directing the light along a first path, separating means disposed in said first path for transmitting therealong a portion of the incident

visible light and for reflecting the remaining portion of the visible light and substantially all of the incident infrared light into a second path which intersects said first path, intensifying means disposed along said second path for converting the visible and infrared light therein to a visible intensified light, and combining means disposed at the intersection of said first and second paths for transmitting along said first path the unintensified portion of the incident visible light therein and for reflecting the intensified light into said first path rearwardly of said separating means.

CLAIM 39. The night vision apparatus of Claim 38, wherein each of said separating means and said combining means comprises a dichroic prism.

CLAIM 40. The night vision apparatus of Claim 39, wherein each of said dichroic prisms has a dichroic coated surface, said coated surfaces being substantially parallel and spaced apart a predetermined slight distance.

CLAIM 41. The night vision apparatus of Claim 39, wherein said dichroic prism of said separating means transmits at least 50% of the incident visible light and reflects between 90% and 100% of the incident infrared light, said intensified light lying in a predetermined relatively narrow band of wave lengths, said dichroic prism of said combining means reflecting substantially all of the intensified light and transmitting

substantially all the light outside said predetermined band.

CLAIM 42. The night vision apparatus of Claim 38, wherein said second path is a folded path.

CLAIM 43. The night vision apparatus of Claim 42, and further including objective lens means and eyepiece lens means disposed along said second path respectively forwardly and rearwardly of said intensifying means.

CLAIM 44. The night vision apparatus of Claim 43, and further including inverting lens means disposed between said intensifying means and said eyepiece lens means for inverting the image from said intensifying means.

CLAIM 45. In night vision apparatus for receiving at an entrance plane visible and infrared light from a viewed object and forming an intensified image of the object along a viewing axis of a viewer's eye, the improvement comprising: means defining a first optical path along the viewing axis from the entrance plane to the viewer's eye, means defining a second optical path from the entrance plane and intersecting said first path, said second path having a folded portion lying in a plane which is non-parallel to said first path, intensifying means disposed along said folded portion of said second path for converting the visible and infrared light therein to a visible intensified light, and combining means disposed at the intersection of said first and

second paths for reflecting said intensified light from said second path into said first path toward the viewer.

CLAIM 46. The night vision apparatus of Claim 45, wherein said combining means comprises a dichroic prism.

CLAIM 47. The night vision apparatus of Claim 45, wherein said second path has an input portion disposed substantially parallel to said first path, said folded portion lying in a plane disposed substantially perpendicular to said first path.

CLAIM 48. The night vision apparatus of Claim 45, and further including objective lens means and eyepiece lens means disposed in said folded portion of said second path respectively forwardly and rearwardly of said intensifying means.

CLAIM 49. In night vision binocular goggles for receiving at an entrance plane visible and infrared light from a viewed object and forming intensified images of the object along viewing axes of the viewer's eyes, the improvement comprising: a goggle housing adapted to be fitted over the eyes of the viewer; and a pair of optical assemblies mounted in said housing for respectively directing incident visible and infrared light from the viewed object to the eyes of the viewer, each of said optical assemblies including means defining an optical path from the entrance plane to the viewer's eye, said optical path having a first portion which lies along the corresponding viewing axis and a second portion which is

entirely non-parallel to said first portion, and image intensifying means disposed in said second portion of said optical path.

CLAIM 50. The goggles of Claim 49, wherein said second portion of said path is folded and lies in a plane disposed substantially perpendicular to the viewing axis.

CLAIM 51. The goggles of Claim 49, wherein each of said optical assemblies includes objective lens means and eyepiece lens means disposed in said second portion of said path respectively forwardly and rearwardly of said image intensifying means.

CLAIM 52. The goggles of Claim 51, wherein each of said optical assemblies includes focusing means coupled to the associated objective lens means for focusing same.

CLAIM 53. The goggles of Claim 51, wherein each of said optical assemblies includes diopter adjustment means.

CLAIM 54. The goggles of Claim 51, and further including means carried by said housing and coupled to each of said optical assemblies for adjusting the interpupillary distance therebetween.

CLAIM 55. The goggles of Claim 51, wherein each of said optical assemblies includes means for selectively actuating and deactuating said intensifying means.

CLAIM 56. The goggles of Claim 51, wherein each of said optical assemblies includes means defining a first field

of view for light from said image intensifying means, said optical assembly including means defining a second field of view for the light in said first portion of said path substantially greater than said first field of view.

CLAIM 57. The goggles of Claim 56, wherein said first and second fields of view are substantially circular and concentric.

CLAIM 58. An objective lens system for use in a night vision system, which night vision system includes a bent path through which the incoming light travels, comprising, in combination:

a first negative power group at the first end of the path of ravel of the light;

a positive power group spaced from said first negative power group along the path of travel of the light;

a second negative power group spaced from said positive power group along the path of travel of the light;

means for spacing said positive power group between said first and second negative power groups, and for spacing said second negative power group from said positive power group; and

an entrance located adjacent said first negative power group for admitting the light therethrough to said first negative power group, so that the light travels from said first negative power group to said positive power group and then to said second negative power group.

CLAIM 59. The objective lens system according to Claim 58, wherein said first negative power group comprises a convex lens and a mensiscus lens; said positive power group comprises a meniscus lens, a doublet lens system, and a convex lens system; and said second negative power group comprises a field flattener lens; said second negative power group being mounted such that the axis of the lens thereof is at right angles to the axes of the lenses of said positive power group.

CLAIM 60. The objective lens system according to Claim 58, wherein the central axis of said first negative power group is perpendicular to the central axis of said positive power group, and the central axis of said second negative power group is perpendicular to the central axis of said positive power group.

Fig 1

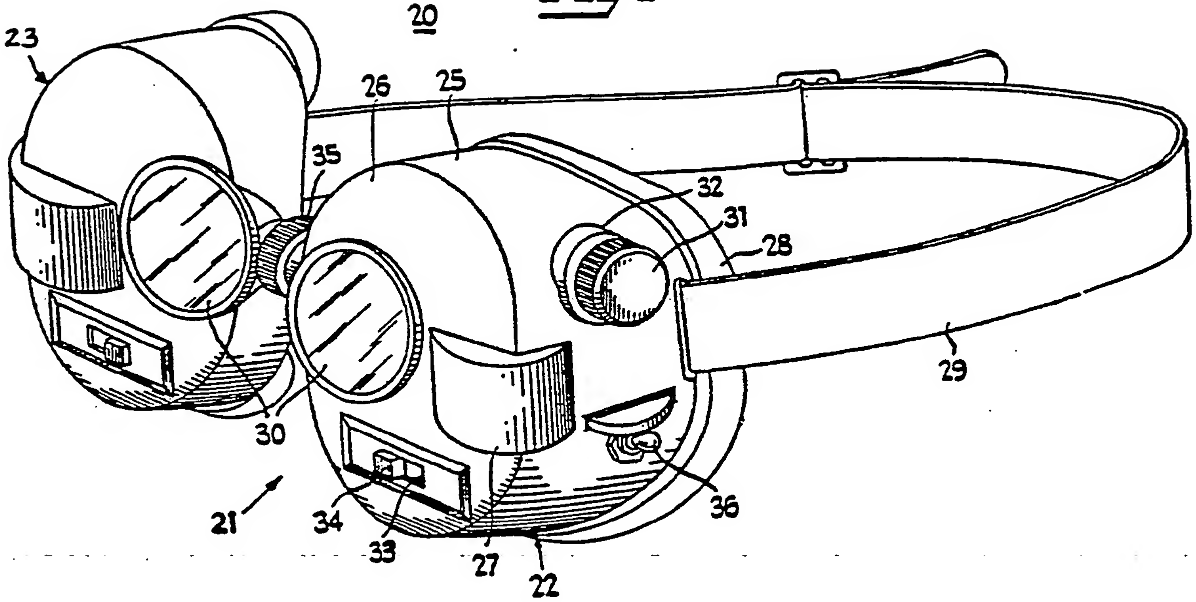
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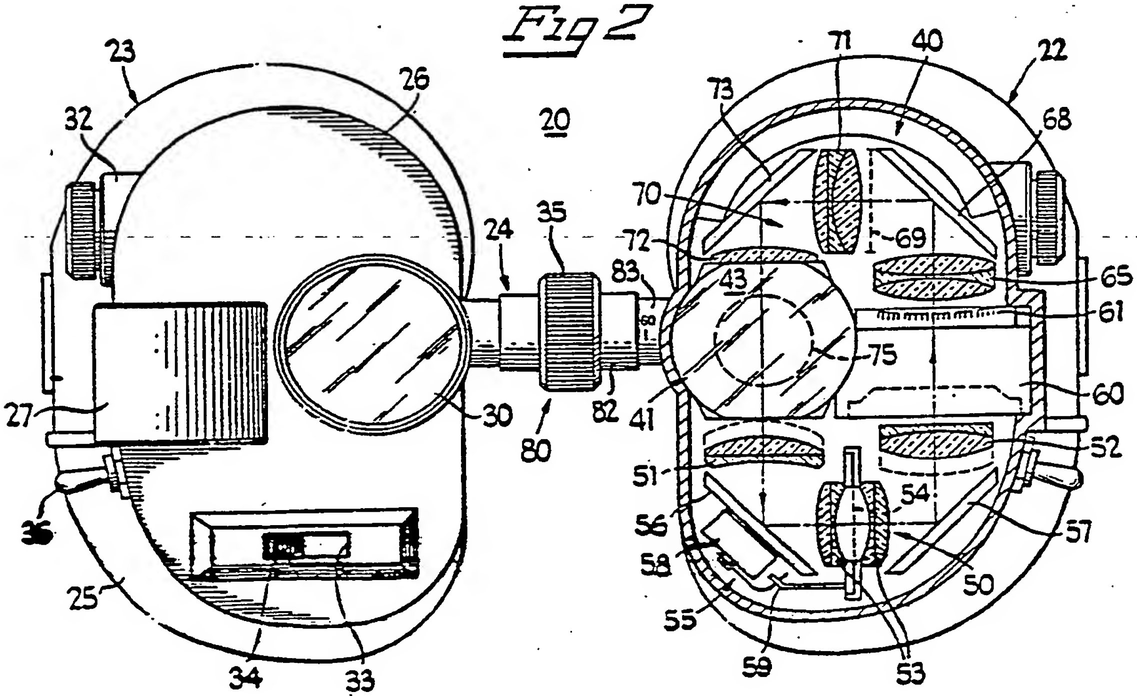
Fig 2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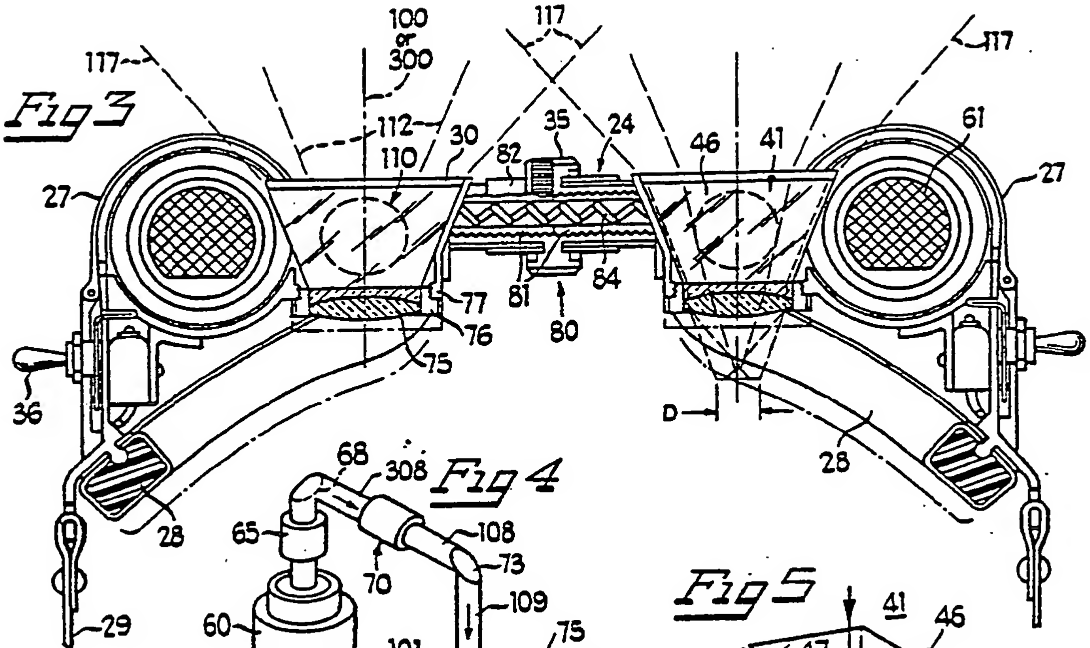


Fig 3

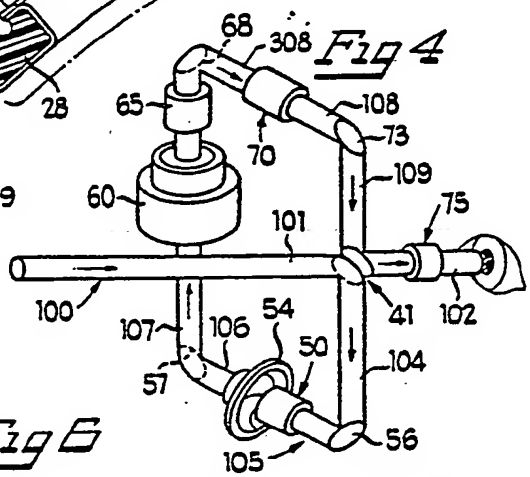


Fig 4

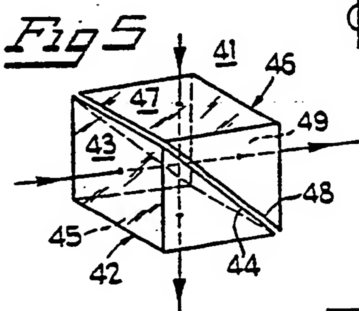


Fig 5

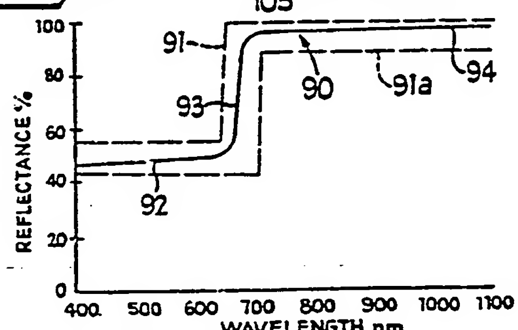


Fig 6

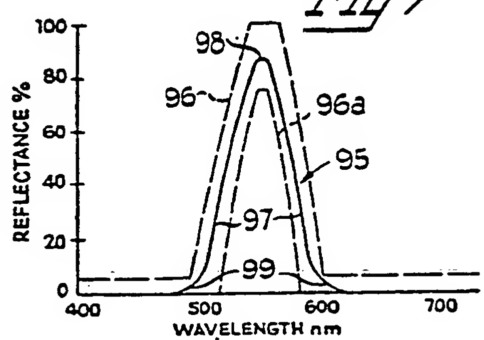


Fig 7

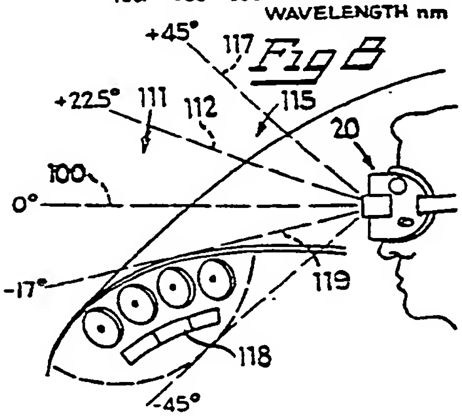


Fig 8

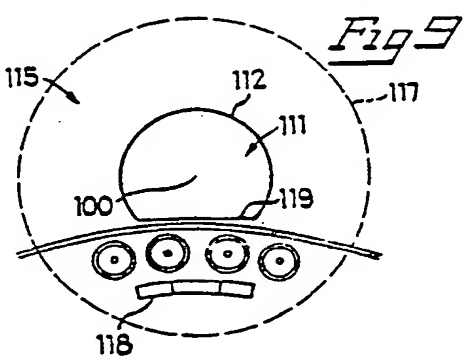


Fig 9

Fig 10

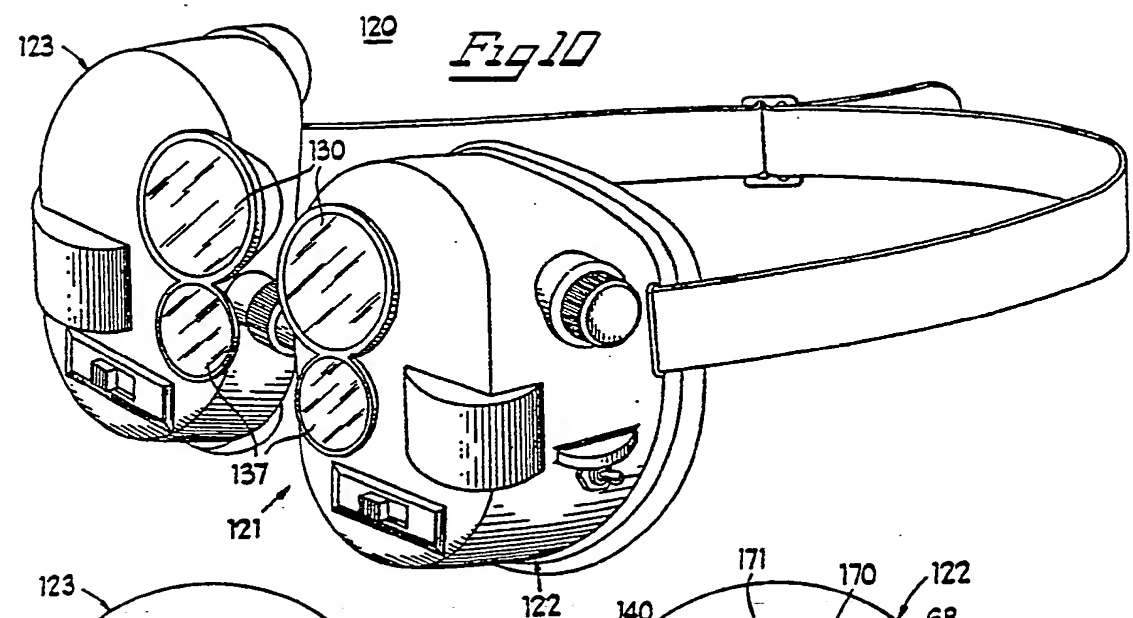


Fig 11

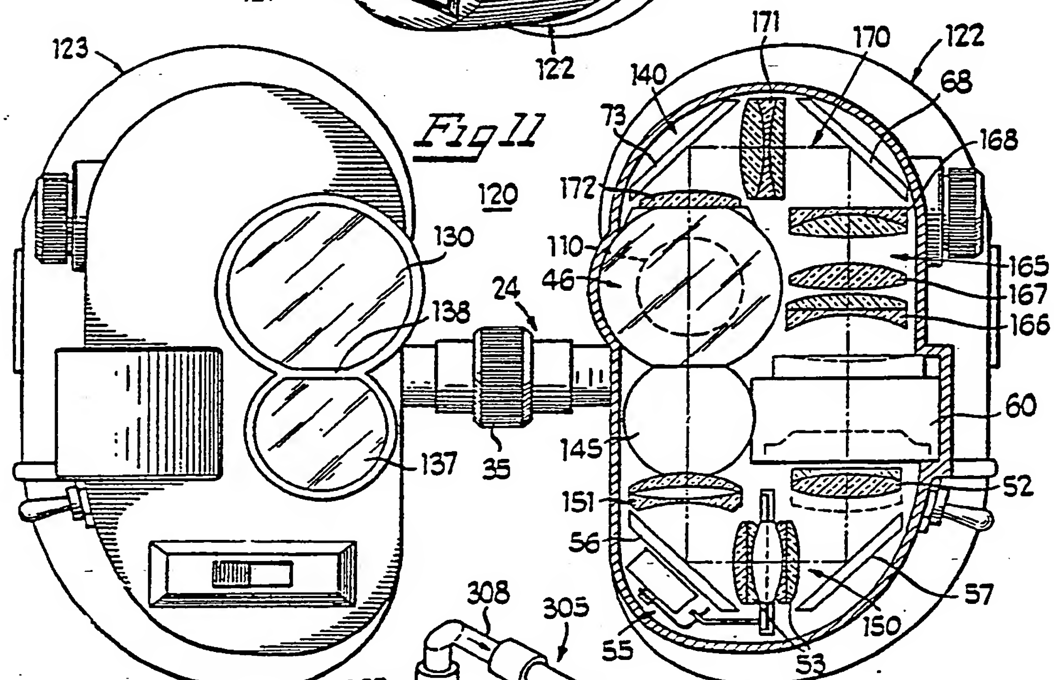
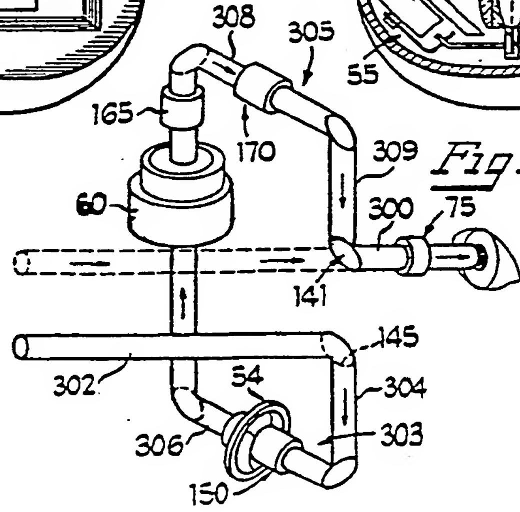


Fig 12



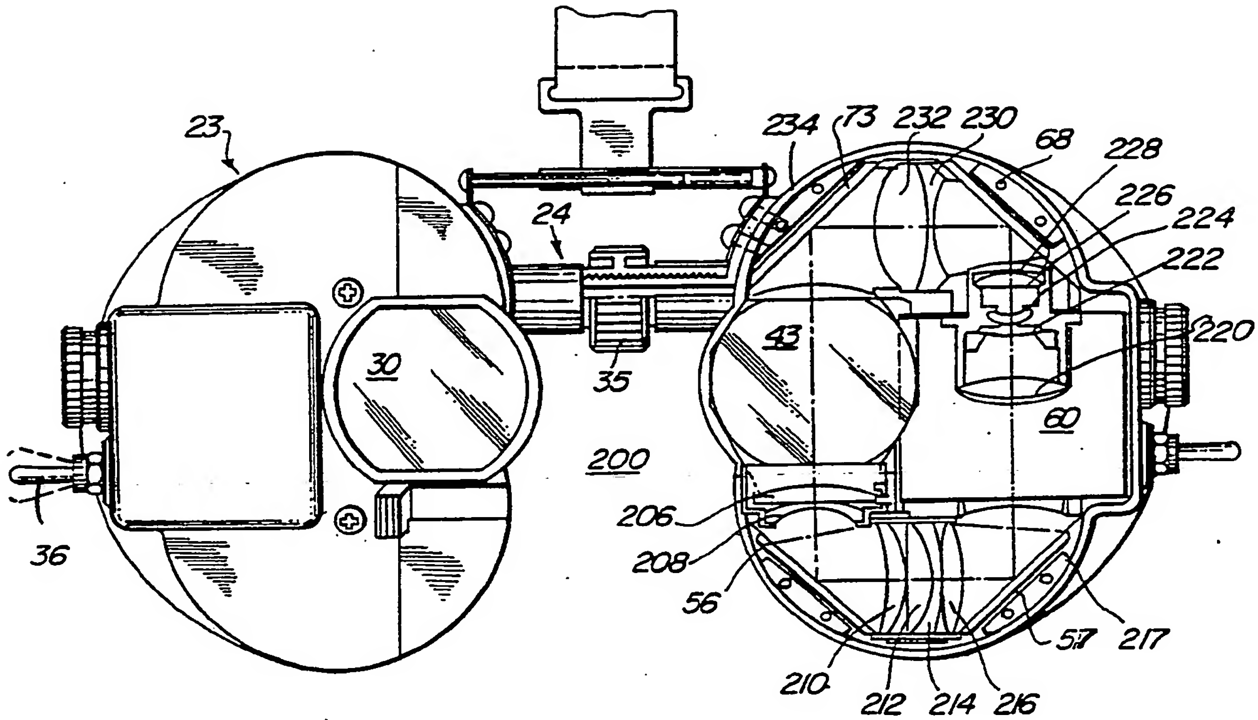

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FIG 13

INTERNATIONAL SEARCH REPORT

International Application No PCT/US86/00437

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC

INT. CL.[4] G02B 23/12, 23/16, 9/12, 25/00
U.S. CL. 350/538, 1.2, 1.4, 410, 412, 474

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	350/538,569,410,412,438,474,1.1-1.4

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
Y A	US,A, 3,907.401. (LIU) 23 September 1975. See entire document	1-8,16-18,58,60 9-15,19-20,59
Y A	US,A, 4,178,075. (ROGERS), 11 December 1979. See entire document	1-8,16-18,58,60 9-15, 19-20,59
Y A	US, A, 3,915,547, (SCIDMORE ET AL) 28 October 1975. See entire document	1-8,16-18,58,60 9-15,19-20,59
Y A	US,A,4,467,190, (HADANI) 21 August 1984. See entire document	16-18,21-58,60 1-15,19-20,59

* Special categories of cited documents: [15]

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
19 May 1986	20 JUN 1986
International Searching Authority [1]	**Signature of Authorized Officer [20]**
ISA/US	Jon W. Henry